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Survey of Flue Gas Desulfurization Systems: Cholla Station, Arizona Public Service Co.

PEDCo-Environmental, Inc, Cincinnati, Ohio

Prepared for

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16. ABSTRACT The report gives results of a second survey of the flue gas desulfurization (FGD) system on Unit 1 of Arizona Public Service Co.'s Cholla Station. The FGD system, commercially available in December 1973, utilizes a limestone slurry in two parallel scrubbing modules to control SO2 and fly ash from the combustion of low sulfur western coal. (The two-module FGD system is described.) The system's total SO2 removal efficiency is 58.5% (92% for the SO2 removal module). Either or both modules can be bypassed. The flue gas cleaning wastes are disposed of in an on-site unlined fly ash pond. No water is recycled from the pond to the FGD system. Following a number of modifications of the FGD system by the system supplier and the utility, the system has exhibited a high degree of mechanical reliability while meeting required SO2 and particulate emission control levels.

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Flue Gases	Coal	Stationary Sources	21B 21D
Desulfurization	Combustion	Wet Limestone	07A,07D
Fly Ash	Cost Engineering	Particulate	14A
Limestone	Sulfur Dioxide		07B
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by

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SUMMARY

The wet limestone flue gas desulfurization (FGD) system on Boiler 1 at the Cholla Steam Electric Station of the Arizona Public Service Company (APS) was designed and installed by Research-Cottrell (R-C).

Research-Cottrell had previously conducted pilot plant operations at the Cholla Station (treating a flue gas slip stream from Boiler 1), but their work on a full-scale FGD system did not begin until January 1971. They prepared preliminary design and submitted a proposal to APS in April 1971 and were awarded the contract in July.

Construction and initial testing were not completed until December 3, 1973. Construction was delayed for several reasons: changes in engineering design and material specifications, equipment delivery delays, adverse weather conditions, system shakedown problems, and problems with the FGD system at APS's Four Corners Station.

Commercial operation of the FGD system commenced on December 14, 1973, and has proceeded on a continuous basis since that time. Cholla Boiler 1 is a base-load unit with a maximum, continuous, net generating capacity of 115 MW when the unit is tied into the FGD system. At full load it consumes pulverized coal at a rate of approximately 49 Mg (54 tons) per hour. The fuel burned in this unit is a low-sulfur, New Mexico coal with the following average characteristics: 23.6 MJ/kg (10,150 Btu/lb) heat content; 0.5 percent sulfur; and 13.45 percent ash.

The FGD system consists of two parallel modules (A and B), each designed to accomodate 50 percent of the boiler flue gas. Module A includes a variable-throat, flooded-disc scrubber for particulate control, followed by a packed tower that uses a

limestone slurry for sulfur dioxide removal. The limestone absorbent is purchased primarily from the Superior Company in Phoenix, Arizona.

Module B differs from Module A only in that the absorber tower is not packed and limestone slurry is not circulated through it. Module A is designed for 92 percent sulfur dioxide removal efficiency and Module B for 25 percent. This yields a combined sulfur dioxide removal efficiency of 58.5 percent. This efficiency is based on an inlet sulfur dioxide concentration of approximately 400 to 500 ppm. Either or both modules can be bypassed. Gas leakage around each module is approximately 4.5 percent of the volume of the gas being treated.

The Munters packing in the Module A tower is 0.6 m (2 ft) thick and constructed of polypropylene corrugated sheets joined together in a crisscross pattern similar to a honeycomb. The mist eliminators are also constructed of polypropylene. The three bundles of shell-and-tube steam reheaters are 316L stainless steel.

The Cholla Steam Electric Station does not have a sludge treatment or fixation system. The sludge and fly ash are pumped to an unlined, pre-existing fly ash pond in a common pipeline. The FGD system operates on an open-water-loop basis that does not require the recycling of water from the pond. Fresh makeup water required to maintain the water balance in the scrubbing system is 0.07 liters/sec per MW (1.04 gpm/MW).

According to Research-Cottrell, the particulate and SO_2 collection efficiencies of Module A were 99.7 and 92 percent during a test run. As of December 1977, APS had not conducted an official acceptance test on the system.

Minor modifications were made as a result of initial testing, and the system was officially placed in service on December 14, 1973. It operated with a 92.6 percent reliability factor until April 15, 1974, when the system was shut down for approximately 2 weeks for scheduled modifications of the expansion joints. Research-Cottrell repair crews were available during

most of the first half of 1974, and it is believed that their attention to maintenance was partly responsible for the high system reliability demonstrated during the shakedown period.

The performance of the system from the completion of final modifications in October 1973 through December 1977 indicates a high degree of mechanical reliability. Shutdowns have occurred primarily during scheduled turbine, boiler, and FGD system overhauls. The average reliability indexes for the total FGD system in 1974, 1975, 1976, and 1977 were 91, 88, 88, and 95 percent, respectively. Reliability indexes for Module A in the same years were 94, 91, 89, and 93 percent, and for Module B, 88, 85, 89, and 97 percent.

Total installed capital cost of the Cholla FGD system to date is approximately $6.5 million or $57/kW (1973 dollars). This cost figure is not final because final performance tests have not been conducted and APS has not yet accepted the system. The capital cost figure includes engineering costs, site preparation, erection, electrical service, limestone handling facilities, and pilot plant engineering.

Annual operating costs are estimated to be 2.2 mills/kWh. This figure includes a 23 percent charge on capital investment to account for interest, depreciation, taxes, and other fixed charges. Also included are labor costs of 0.09 mills/kWh (one full-time auxiliary operator); utility costs of 0.2 mills/kWh (2.8 MW/hr electricity and 18,000 lb/hr of steam); and material costs of 0.15 mills/kWh (limestone). Maintenance and sludge disposal costs are not included.

Arizona Public Service is now in the process of increasing the station's power generating capacity from 115 to 1315 MW. Units 2 and 3, now under construction, are scheduled for commercial start-up in June 1978 and June 1979. Each is rated at 250 MW. Units 4 and 5, now in the planning stage, are scheduled for commercial start-up in June 1980 and June 1983. Each of these units is rated at 350 MW. Current emission control regulations require that three of the additional units (2, 4, and

5) have FGD-equipped boilers. Research-Cottrell has been awarded two separate contracts to provide additional FGD systems for Units 2 and 4. Although Unit 5 is still in the preliminary design stage, it is expected to include an FGD system. No FGD system is required on Unit 3; it will have only an electrostatic precipitator (ESP) for particulate control.

Table 1 summarizes general data on Cholla Unit 1.

Table 1. DATA SUMMARY: CHOLLA UNIT 1

Unit rating (net)	115 MW
Fuel	Coal
Average fuel characteristics[a]	
Heating value	23.6 MJ/kg (10,150 Btu/lb)
Ash	13.45 %
Sulfur	0.52 %
FGD system supplier	Research-Cottrell
Process	Limestone slurry
New or retrofit	Retrofit
Start-up date	October 1973
Modules	Two[b]
Efficiency	
Particulates	99.7 %[c]
Sulfur dioxide	58.5 %[d]
Water makeup	0.07 liters/sec per MW (1.04 gpm/MW)
Sludge disposal	Unstabilized sludge disposed of on site in pre-existing ash disposal pond.
Unit cost[e]	
Capital	$57/kW
Annual	2.2 mills/kWh

[a] Average values of coal burned during 1975 operation.

[b] Only one module (A) is equipped with packing and limestone slurry circulation for sulfur dioxide removal.

[c] Total particulate removal efficiency provided by mechanical collectors and venturi scrubbers.

[d] Total system removal efficiency. Module A efficiency is 92 percent; Module B, 25 percent.

[e] 1973 dollars.

SECTION 1

INTRODUCTION

The Industrial Environmental Research (IERL) Laboratory of the U.S. Environmental Protection Agency (EPA) has initiated a study to evaluate the performance characteristics and reliability of flue gas desulfurization (FGD) systems operating on coal-fired utility boilers in the United States.

This report, one of a series on such systems, covers the Cholla Steam Electric Station of Arizona Public Service Company (APS). It includes pertinent process design and operating data, a description of major start-up and operational problems and solutions, atmospheric emission data, and capital and annual cost information.

This report is an update of a previous report based on observations made during an April 2, 1974, plant inspection and on data provided by the utility and the system supplier during that visit. This update report is based on a second plant visit on April 8, 1976, and data obtained since that visit. Information presented is current as of December 1977.

Section 2 presents pertinent facility design and operation data and actual and allowable particulate and sulfur dioxide emission rates; Section 3 describes the FGD system; and Section 4 analyzes FGD system performance. Appendices A and B contain details of plant and system operation and photos of the installation.

SECTION 2

FACILITY DESCRIPTION

The Cholla Steam Electric Station of APS is in an arid desert region in Navajo County, Arizona, near Joseph City. The terrain surrounding the station is relatively flat and sparsely populated. There is no other major industry in the area.

Cholla now operates only one steam turbine generating unit (Boiler 1). This Combustion Engineering (CE) boiler is a dry-bottom, pulverized-coal-fired unit with a net generating capacity of 115 MW. It was put in commercial service in May 1962.

Arizona Public Service is in the process of increasing the Station's capacity from 115 to 1315 MW. Units 2 and 3, now under construction, are scheduled for commercial start-up in June 1978 and June 1979. Each is rated at 250 MW. Units 4 and 5, now in the planning stage, are scheduled for commercial start-up in June 1980 and June 1983. Each of these units is rated at 350 MW. All are CE pulverized-coal-fired units.

The plant burns low-sulfur subbituminous coal from the McKinley mine near Gallup, New Mexico. It is shipped in by rail. A typical analysis of this coal gives the following values: heating value, 10,400 Btu/lb; sulfur content, 0.5 percent; chloride content, 0.025 percent; ash content, 13.5 percent; and moisture content, 15 percent. Table 2A shows monthly average analyses of the coal burned.

Boiler 1 is equipped with mechanical collectors upstream from the FGD system. These R-C multicyclones are designed to remove 80 percent of the inlet particulate matter. If design efficiency is achieved, loading at the outlet of the mechanical collectors should be approximately 2.2 g/m^3 (2.0 gr/scf).

Table 2A. AVERAGE MONTHLY ANALYSES OF COAL BURNED IN 1975

CHOLLA STEAM ELECTRIC STATION

Month	Sulfur, %	Chloride (range), %	Ash, %	Heating value, MJ/kg	Heating value, (Btu/lb)	Average moisture, %
Jan.	0.56	0.01-0.04	13.51	23.5	(10,093)	15
Feb.	0.55	0.01-0.04	14.15	22.6	(9,750)	15
Mar.	0.51	0.01-0.04	22.49	20.9	(9,970)	15
Apr.	0.52	0.01-0.04	17.69	22.5	(9,671)	15
May	0.51	0.01-0.04	11.26	23.4	(10,053)	15
June	0.56	0.01-0.04	12.33	24.1	(10,352)	15
July	0.55	0.01-0.04	9.76	24.6	(10,578)	15
Aug.	0.51	0.01-0.04	11.46	23.3	(10,001)	15
Sept.	0.54	0.01-0.04	9.88	23.7	(10,199)	15
Oct.	0.49	0.01-0.04	12.40	23.7	(9,956)	15
Nov.	0.48	0.01-0.04	14.60	23.1	(9,946)	15
Dec.	0.46	0.01-0.04	11.89	23.7	(10,178)	15
Average	0.52	0.01-0.04	13.45	23.1	(10,150)	15

Arizona State Department of Health Regulation No. 7-1-3.5 limits particulate emissions to 84.27 ng/J (0.196 lb/10^6 Btu) of heat input to the boiler. Arizona Public Service reports present particulate emissions at Cholla are 11.18 ng/J (0.026 lb/10^6 Btu).

Regulation No. 7-1-4.2 limits SO_2 emissions to 430 ng/J (1.0 lb/10^6 Btu) of heat input to the boiler. The present emission rate, based on a combined FGD removal efficiency of 58.5 percent, is estimated to be 185 ng/J (0.43 lb/10^6 Btu).

Based on limits imposed by current emission regulations, three of the four additional units (2, 4, and 5) planned for this station must be equipped with FGD systems. Arizona Public Service has already awarded two separate contracts to R-C for limestone slurry FGD systems on Units 2 and 4. Each system will consist of four modules for the control of particulates and sulfur dioxide. Both FGD systems will have 100 percent capacity, and both are scheduled to go on line simultaneously with the boilers (Unit 2 in June 1978 and Unit 4 in June 1980). Unit 3 will include only an ESP for the control of particulate emissions. The emission control strategy for Unit 5 has not yet been determined.

Table 2B presents pertinent plant design, operation, and emission data.

Table 2B. DESIGN, OPERATION, AND EMISSION DATA,

CHOLLA BOILER 1

Total rated generating capacity	115 MW
Boiler manufacturer	Combustion Engineering
Year placed in service	1962
Unit heat rate	10,199 kJ/net kWh (9,670 Btu/net kWh)
Coal consumption	49 Mg/hr (54 tons/hr
Maximum heat input	1156 GJ/hr (1096 10^6 Btu/hr)
Stack height above grade	76 m (256 ft)
Design maximum flue gas rate	227 m^3/sec (480,000 acfm)
Flue gas temperature	136°C (276°F)
Emission controls:	
Particulate	Mechanical collectors and venturi scrubbers
Sulfur dioxide	Venturi scrubber and packed-bed absorber
Paritculate emission rates:	
Allowable	84.27 ng/J (0.196 lb/10^6 Btu)
Actual	11.18 ng/J (0.026 lb/10^6 Btu)
Sulfur dioxide emission rates:	
Allowable	430 ng/J (1.0 lb/10^6 Btu)
Actual	185 ng/J (0.43 lb/10^6 Btu)

SECTION 3

FLUE GAS DESULFURIZATION SYSTEM

PROCESS DESCRIPTION

The FGD system consists of two modules, A and B. Each module includes a flooded-disc venturi scrubber, a cyclonic mist eliminator, an absorber tower, and a final mist eliminator. The absorber on Module A includes packing for removal of the sulfur dioxide with circulating limestone slurry. The absorber tower in Module B is a hollow spray tower, and limestone slurry is not circulated through it. Each module treats approximately one-half of the total boiler flue gas. A simplified process flow diagram of the entire FGD system is shown in Figure 1. A simplified process flow diagram of Module A, which provides the primary sulfur dioxide control, is shown in Figure 2.

Gas Circuit

Flue gas from the boiler induced-draft (ID) fans is pressurized by two booster fans to a static pressure of approximately 6.2 kPa (25 in. H_2O), then flows downward through the throat of the venturi-type, flooded-disc particulate scrubber. Limestone slurry flows out over the disc and is atomized as it is sheared by the gas stream at the edge of the disc. Slurry is also injected tangentially through nozzles on the inside wall of the venturi scrubber shell above the tapered throat. The orifice is formed by the annular space between the circumference of the horizontal disc and the wall of the tapered duct section in the throat area. The disc is adjusted in the vertical plane within the tapered duct to increase or decrease the area of the orifice. In this manner gas pressure drop and the resulting particulate scrubbing efficiency are controlled. The saturated, scrubbed flue gas then passes through a cyclonic mist eliminator, where

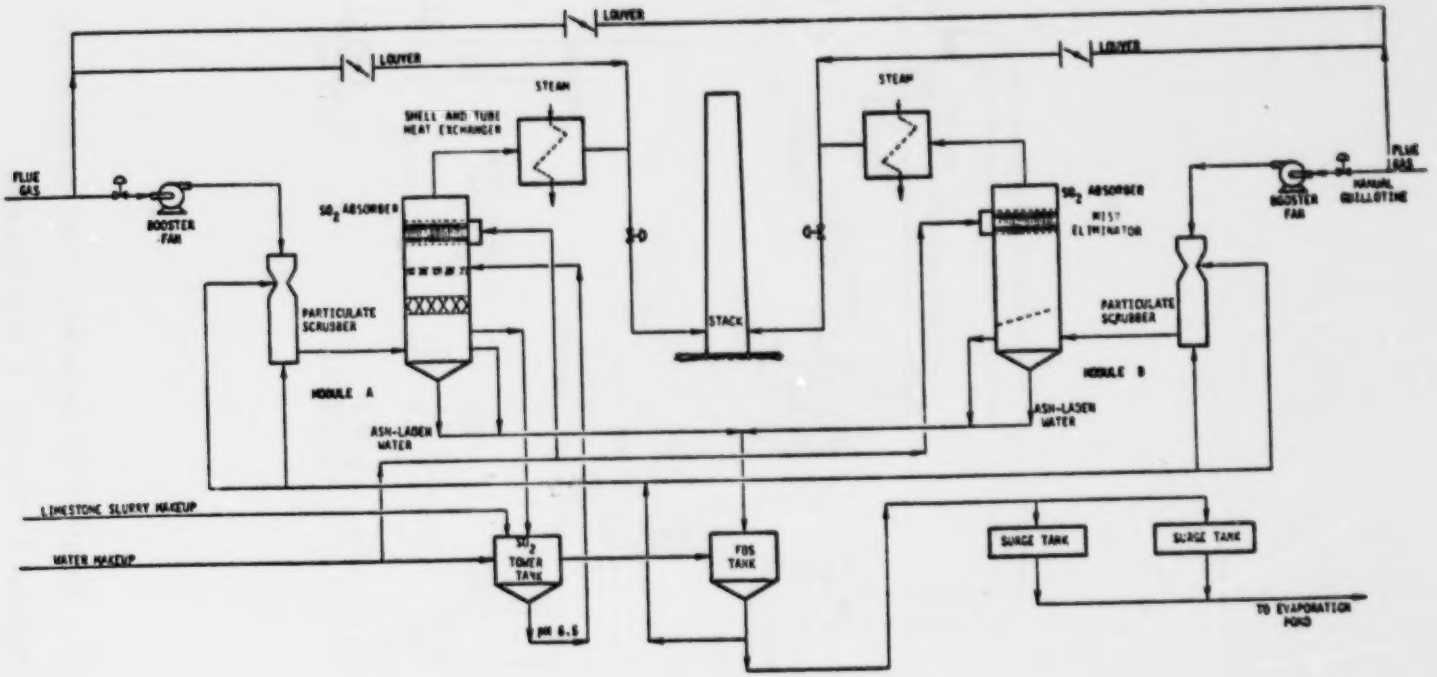

Figure 1. Simplified process flow diagram, Cholla 1 FGD system.

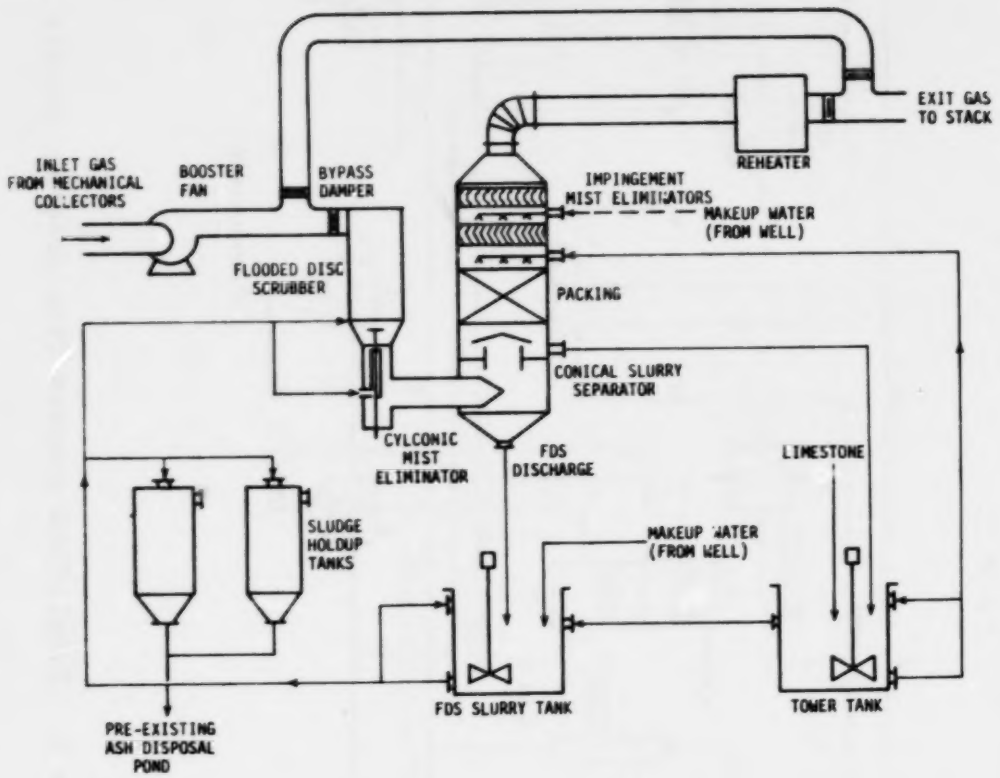

Figure 2. Simplified process flow diagram of Module A, Cholla 1 FGD system.

solids from collected fly ash, limestone slurry, and reaction products are separated from the gas stream before it enters the absorber. A diagram of a Cholla flooded-disc venturi and cyclonic mist eliminator is provided in Figure 3.

Gas from the cyclonic mist eliminator enters the absorber tower near the base. In Module A only, it contacts the limestone slurry on the surface of the wetted-film Munters packing, which is 0.6 m (2 ft) thick.

The packed tower section is separated from the cyclonic mist eliminator by a plate containing a conical hat. This arrangement permits the flue gas to leave the cyclonic mist eliminator and enter the packed spray section and yet prevents the spent limestone slurry in the packed spray section from combining with the spent scrubbing solution from the flooded-disc venturi (see Figure 2). Thus, fly ash cannot enter the absorber tower.

The scrubbed gas then passes through a set of mist eliminators (one set per absorber) and is reheated before it is discharged to the atmosphere through the main stack. The mist eliminators are slat (special baffle design) impingement type, constructed of polypropylene and arranged horizontally (vertical gas flow) in two stages. Reheat is provided by a set of steam-heated, shell-and-tube heat exchangers (one set per module). Each set of reheaters contains two bundles of tubes, which raise the temperature of the saturated gas stream from 49°C (120°F) to 71°C (160°F) before it passes through a duct to the brick-lined, concrete stack.

Limestone is added to Module A of the FGD system at a rate of approximately 110 percent of the stoichiometric requirement for reaction with the sulfur dioxide in the flue gas. Part of the circulated liquor in the sulfur dioxide absorber is diverted to the flooded-disc scrubber tank (common to both modules) to maintain the pH between 4 and 5 in the particulate control system (flooded-disc venturi). The liquid level in this tank is maintained by pumping the excess spent liquor to one of two surge tanks (sludge holdup-tanks) before it is discharged to a pre-

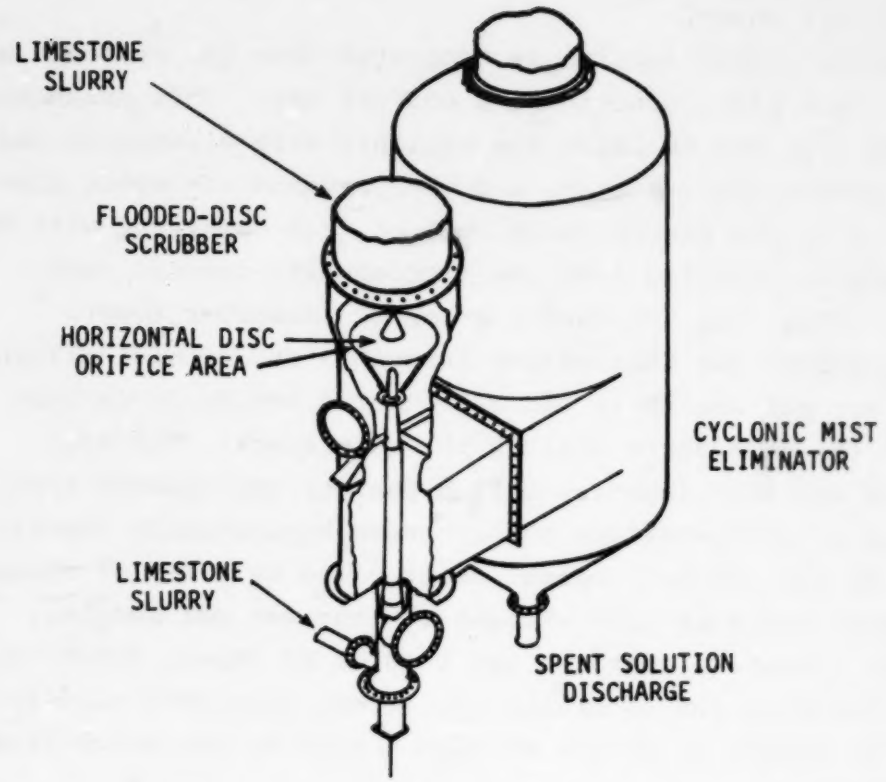

Figure 3. Basic components of the variable-throat, flooded-disc venturi scrubber and cyclonic separator, Cholla FGD system.

existing pond. The plant site has no facilities for sludge storage or fixation. Because of the area's light rainfall and a high evaporation rate, wastewater discharge into receiving waters is not a problem. Therefore no liquor is recirculated back to the process.

Dampers in the FGD system are arranged so that only Module B can be bypassed, or both Modules A and B can be bypassed simultaneously. Module A alone can only be bypassed for short periods of time, however, because limestone, which enters the system in the Module A absorber tower tank, is used to control the operating pH of the entire particulate scrubber system to a range of 4 to 6. The inlets to both modules from the booster fans are interconnected through a common suction header. Flue gas flow control to both modules is maintained by balancing the module fans via amperage control. Figure 4 presents a diagram of the Cholla FGD system damper arrangement.

DESIGN PARAMETERS

The R-C FGD system at Cholla is designed to treat 227 m^3/sec (480,000 acfm) of flue gas at 136°C (276°F). Actual boiler flue gas flow to both modules (at 115-MW generating capacity) measures approximately 189 m^3/sec (400,000 acfm). In addition, bypass leakage around the FGD system amounts to 8 m^3/sec (17,000 acfm).

The flooded-disc particulate scrubbers are constructed of 316L stainless steel and are 1.8 m (6 ft) in diameter by 13.7 m (45 ft) high. Pressure drops on each is 2.5 kPa (15 in. H_2O). Each scrubber operates with a liquid recirculattion rate of about 137 liters/sec (2170 gpm) at full load, which is equal to a liquid-to-gas (L/G) ratio of 1.4 liters/m^3 (10.1 gal/1000 ft^3) at 50°C (122°F). Two-thirds of the scrubbing solution used in the flooded-disc scrubbers is introduced through the hollow shaft of the flooded disc; the remainder is sprayed through tangential nozzles on the vessel wall.

The absorber towers are constructed of 316L stainless steel and are 6.7 m (22 ft) in diameter by 21.3 m (70 ft) high. The

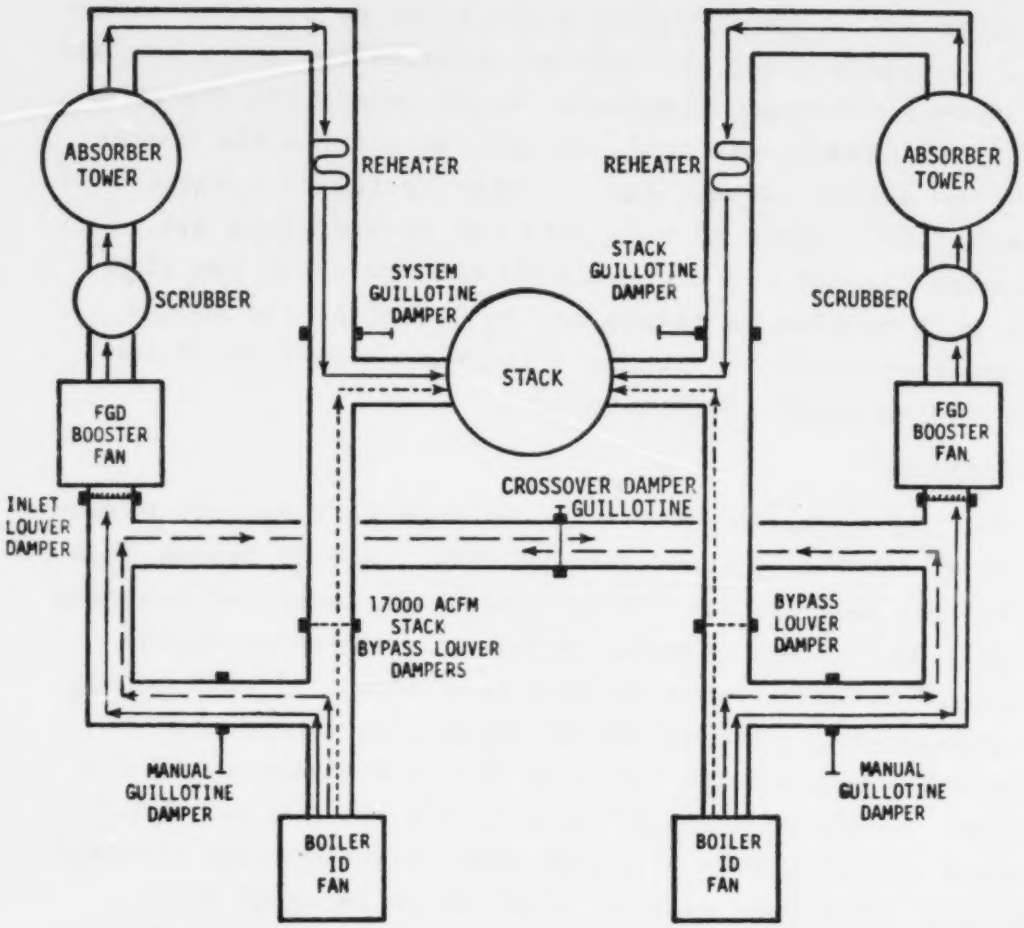

Figure 4. Gas flow and damper arrangement,

Cholla 1 FGD system.

sulfur dioxide absorber in Module A includes a fixed plate and conical hat separator and packing. The fixed plate and conical hat separator are also constructed of 316L stainless steel. The Munters packing, which consists of a fixed matrix of rigid sheets of polypropylene, has a high specific surface area and low pressure drop [0.12 kPa (0.5 in. H_2O)]. The superficial gas velocity of the sulfur dioxide absorber is 2.1 m/sec (6.9 ft/sec), and the L/G ratio is 6.5 liters/m^3 (48.9 gal/1000 ft^3).

The mist eliminators in each absorber tower are arranged horizontally in two stages. The first stage is a Chevron-type, two-pass, polypropylene mist eliminator, and in the SO_2 absorber is approximately 3.7 to 4.6 m (12 to 15 ft) above the packing. The design configuration of the second-stage, four-pass, polypropylene mist eliminator differs only slightly from that of the first stage. The distance between stages is approximately 1.2 m (4 ft). Vane spacing is 3.8 cm (1.5 in.) in the first stage and 18.1 cm (8.1 in.) in the second stage. On each tower, both stages of the mist eliminator are washed on timed cycle with makeup water from plant wells. A quadrant of each mist eliminator stage is sprayed sequentially for 45 seconds every 30 minutes with 520 kPa (60 psig) makeup water. Flow rate of the makeup water to the mist eliminator is approximately 15 liters/sec (240 gpm).

The set of shell-and-tube heat exchangers on each module raises the temperature of the gas from 50°C (122°F) to 72°C (162°F) before it is discharged to the atmosphere. Each reheater consists of two bundles of 316L stainless steel bare tubes with an outside diameter of 2.5 cm (1.0 in.). The heating medium is high-pressure steam extracted from the boiler steam drum, which is reduced in pressure from 13.2 MPa (1900 psig) to 1.8 MPa (250 psig). The reheater rating is approximately 84 GJ/hr (8 million Btu/hr). Reheater steam power requirements are equivalent to approximately 2 MW of electrical capacity. [Six steam soot blowers are operated 5 minutes during each 8-hour period (once per shift) to clean the tubes.]

The reheated, scrubbed gases are discharged through carbon steel ducts to the main stack. The ducts from each module enter the stack at points directly opposite each other (see Figure 4). The stack shell is constructed of brick-lined concrete.

Tables 3 through 7 summarize design and operating parameters for the major components of the Cholla FGD system.

LIMESTONE MILLING FACILITIES

Most of the ground limestone for the FGD system is supplied by the Superior Company in Phoenix, Arizona. The grade supplied, known as "red wall" limestone, meets size specifications of at least 75 percent by weight less than 200 mesh. Chemical composition specifications call for a minimum calcium oxide content of 52.5 percent, a guaranteed minimum calcium carbonate content of 95 percent, and maximum magnesium carbonate and silica contents of 0.5 and 1.0 percent.

The finely ground limestone is stored in a silo on the plant grounds, from which it is discharged at a rate of 9 kg/min (20 lb/min) into a slurry preparation tank at the base of the silo. The fresh limestone slurry is introduced into the FGD system through the sulfur dioxide absorber recirculation tank.

Arizona Public Service is in the process of installing a limestone grinding facility on the plant grounds. This facility will be able to meet present (Unit 1) and future (Unit 2) limestone requirements. It will consists of a ball mill capable of grinding 0.6 cm (0.25 in.) limestone rock delivered to the plant by rail to the specified size of 75 percent minus 200 mesh.

PROCESS CHEMISTRY: PRINCIPAL REACTIONS

The chemical reactions involved in the Cholla wet limestone scrubbing process are highly complex. Although details are beyond the scope of this discussion, the principal chemical mechanisms are described below.

The first and most important step in the wet-phase absorption of sulfur dioxide from the flue gas stream is diffusion from

Table 3. DATA SUMMARY: PARTICULATE AND SO_2 SCRUBBERS

	Flooded-disc scrubber	SO_2 absorber tower
L/G ratio, liters/m^3 (gallons/1000 acf)	1.35 (10.1)	6.5 (48.9)
Superficial gas velocity, m/sec (ft/sec)		2.1 (6.9)
Equipment sizes	1.8 m (6 ft) dia. x 13.7 m (45 ft)	6.7 m (22 ft) dia. x 21.3 (70 ft)
Equipment internals	Adjustable disc	0.6 m (2 ft) fixed matrix packing

Table 4. DATA SUMMARY: FGD SYSTEM HOLD TANKS

	Flooded disc scrubber holdup tank	SO_2 absorber towers holdup tank	FGD system sludge holdup tank	Limestone slurry makeup tank
Total number of tanks	One	One (common)	Two	Two
Tank sizes	3.8 m (12.5 ft) dia. x 4.3 m (14 ft)	8.3 m (27.3 ft) dia. x 8.5 m (28 ft)	5.6 m (18.5 ft) dia. x 8.2 m (27 ft)	
Retention time at full load	7 min	5 min	14 hr	
Temperature	49°C (121°F)	49°C (121°F)	49°C (121°F)	32°C (90°F)
pH	5.2	6.5	5.2	
Solids concentration, percent	15.5	8.3	25	20
Specific gravity	1.102	1.049		

Table 5. DATA SUMMARY: FGD SYSTEM MIST ELIMINATORS

Number	Two
Materials of construction	Polypropylene
Type	Chevron (1st stage) Special design (2nd stage)
Number of stages	Two
Passes/stage	Two (1st stage) Four (2nd stage)
Distance between stages	1.2 m (4 ft)
Vane spacing	3.8 cm (1.5 in.) (1st stage) 18.1 cm (7.1 in.) (2nd stage)
Distance between last absorber stage and mist eliminator	3.7 to 4.6 m (12 to 15 ft)
Wash system:	
Water	Plant well
Frequency	Intermittent (45 seconds every 30 min per quadrant)
Pressure	520 kPa (60 psig)
Capacity	15 liters/sec (240 gpm)

Table 6. DATA SUMMARY: FGD SYSTEM REHEATERS

Number	Two
Type	Shell-and-tube
Heating medium	Steam
Number of tubes per exchanger	Two
Tube size, outside diameter	2.5 cm (1.0 in.)
Material of construction	316L stainless steel
Heating medium characteristics:	
Source	Boiler steam drum
Pressure	1.8 MPa (250 psig)
Temperature	Saturated
Consumption	9,100 kg/hr (20,000 lb/hr)
Rating	84 GJ/hr (8 million Btu/hr)
Soot blowers:	
Medium	Steam
Number	Six
Frequency	5 min/8-hr period
Energy requirement, percent of unit output	2

Table 7. TYPICAL PRESSURE DROP ACROSS COMPONENTS OF PARTICULATE SCRUBBER AND PACKED TOWER

	Pressure drop, kPa (in. H_2O)
Flooded-disc scrubber	2.5 (10.0)
Sulfur dioxide absorber	0.1 (0.5)
Mist eliminator	0.1 (0.5)
Reheater	0.5 (2.0)
Ductwork	1.3 (5.0)
Total	4.5 (18.0)

the gas to the liquid phase. Sulfur dioxide is an acidic anhydride that reacts readily to form an acidic species in the presence of water

$$SO_2 \uparrow \rightleftharpoons SO_2(aq.)$$

$$SO_2(aq.) + H_2O \rightleftharpoons H_2SO_3$$

In addition, some sulfur trioxide is formed from further oxidation of the sulfur dioxide in the flue gas stream.

$$2SO_2 \uparrow + O_2 \uparrow \rightleftharpoons 2SO_3 \uparrow$$

Because conditions are thermodynamically (but not kinetically) favorable, only small amounts of sulfur trioxide are formed. This species, like sulfur dioxide, is an acidic anhydride that reacts readily to form an acid in the presence of water

$$SO_3 \uparrow \rightleftharpoons SO_3(aq.)$$

$$SO_3(aq.) + H_2O \rightleftharpoons H_2SO_4$$

The sulfurous and sulfuric acid compounds are polyprotic species; the sulfurous species is weak and the sulfuric species is strong. Their dissociation into ionic species occurs as follows:

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^-$$

$$HSO_3^- \rightleftharpoons H^+ + SO_3^=$$

$$H_2SO_4 \rightleftharpoons H^+ + HSO_4^-$$

$$HSO_4^- \rightleftharpoons H^+ + SO_4^=$$

Analogous to the oxidation of sulfur dioxide to form sulfur trioxide, oxidation of sulfite ion by dissolved oxygen in the scrubbing slurry is limited.

$$2SO_3^= + O_2(aq.) \rightleftharpoons 2SO_4^=$$

The limestone absorbent, which is a minimum of 95 percent calcium carbonate by weight, enters the scrubbing system as a slurry with water. It is insoluble in water, and solubility increases only slightly as the temperature increases. When introduced into the scrubbing system, the slurry dissolves and ionizes into an acidic aqueous medium, yielding the ionic products of calcium, carbonate, bicarbonate, and hydrogen.

$$CaCO_3 \downarrow \rightleftharpoons CaCO_3(aq.)$$

$$CaCO_3(aq.) \rightleftharpoons Ca^{++} + CO_3^{=}$$

$$Ca^{++} + H^{+} + CO_3^{=} \rightleftharpoons CaHCO_3^{+}$$

$$CaHCO_3^{+} \rightleftharpoons Ca^{++} + HCO_3^{-}$$

The chemical absorption of sulfur dioxide occurs in the venturi scrubber and spray tower and is completed in the external recirculation tank. The reaction products precipitate as calcium salts and the scrubbing solution is recycled. The following are the principal reaction mechanisms for product formation and precipitation.

$$Ca^{++} + SO_3^{=} \rightleftharpoons CaSO_3$$

$$CaSO_3 + 1/2H_2O \rightleftharpoons CaSO_3 \cdot 1/2H_2O$$

$$Ca^{++} + SO_4^{=} \rightleftharpoons CaSO_4$$

$$CaSO_4 + 2H_2O \rightleftharpoons CaSO_4 \cdot 2H_2O$$

The hydrated calcium sulfite and calcium sulfate reaction products, along with the collected fly ash and unreacted limestone, are transferred to the disposal pond. The supernatant is recycled to the process.

PROCESS CONTROL

The chemistry of the FGD system is maintained by controlling two important parameters of the scrubbing solution, the pH and solids concentration levels. The pH is monitored manually by sampling the scrubbing solution in the tower recirculation tank

once per shift. The solids concentration in the scrubbing loop is controlled by the use of nuclear density meters in the FGD recirculation tank.

The scrubbing solution pH is maintained at a minimum value of 5.0. Control at this level prevents major pH changes in the scrubber, which may change salt saturation levels and cause solids deposition and scale formation on the scrubber internals. The quantity of limestone used in this pH range is approximately 110 percent stoichiometric, resulting in a limestone utilization rate of 90 percent and a sulfur dioxide removal efficiency of approximately 90 percent in the Module A absorber.

The desired solids concentration level in the scrubber circulation loop is 8 to 15 percent. The solids are composed primarily of fly ash, calcium sulfite, calcium sulfate, and calcium carbonate.

Flue gas loadings and sulfur dioxide concentrations are also monitored and controlled in the scrubbing system. The flue gas that flows into the scrubbing trains is controlled using motor amperage monitoring to balance the ID fans. The measurement of the mass flow of the sulfur dioxide into the scrubbing system is performed by two continuous sulfur dioxide monitors.

The FGD system instrumentation is housed in two separate areas. Most of the recording instruments are mounted on a panel in a building housing electrical switch gear, adjacent to the FGD structure. The remaining instruments, primarily for remote control of process operations, are housed in the main boiler control room and are monitored by the boiler control operator.

SECTION 4

FGD SYSTEM PERFORMANCE

PERFORMANCE TEST RUN

Initial testing of the FGD system began on October 2, 1973, as most of the construction had been completed by that time. The system was operated until a scheduled shutdown on October 21. This 3-week test period was used to determine particulate and sulfur dioxide removal efficiencies, mist carryover from the towers, maximum process gas flow rates, and the amount of bypass gas leakage.

Module A, which has the packed tower, achieved a sulfur dioxide removal efficiency of 92 percent with average inlet and outlet sulfur dioxide concentrations of 417 and 34 ppm. Arizona Public Service estimates that Module B, which has an empty tower, is capable of removing 25 percent of the inlet sulfur dioxide. Therefore, the combined sulfur dioxide removal efficiency for the two modules was determined to be 58.5 percent [(92 + 25)/2].

No mist carryover from the scrubbing trains was detectable. Solids carryover in Module A were analyzed for calcium ion and showed an average of 0.177 g/m^3 (0.05 gr/scf). The appearance of the mist eliminators at the end of the test period, together with the carryover tests, indicated very little entrainment of slurry. Pressure drop buildup across the mist eliminator was less than 0.2 kPa (0.7 in. H_2O).

The maximum average inlet gas rates during the 3-week operation were 101 m^3/sec (214,300 acfm) to Module A and 97 m^3/sec (204,600 acfm) to Module B. Air leakage into the system was 9 m^3/sec (18,400 acfm) downstream of the flooded-disc scrubbers.

Chloride ion concentrations were 1600 ppm in the flooded-disc scrubber recirculation and 575 ppm and in the tower slur-

ries. These levels are sufficient to cause pitting corrosion in localized areas when temperatures are greater than 60°C (140°F) and pH is less than 3.0. The chloride content of the coal ranged between 0.01 and 0.04 percent (equivalent to 8 to 32 ppm by weight in the flue gas). The chloride ion concentration was 933 ppm in the boiler water blowdown, which is used as makeup water to the FGD unit. The chloride ion concentration was 144 ppm in the well water, which is used for boiler makeup water and FGD fresh water makeup.

Table 8 presents detailed information and data gathered during the preliminary performance test run.

OPERATION HISTORY: PROBLEMS AND SOLUTIONS

Start-up and operation of the Cholla FGD system have been accompanied by many problems. An analysis of these problems reveals that most were related to process design rather than process chemistry. The utility operators and the FGD system designer have conceived and implemented solutions to many of these problems. The major problems and solutions are discussed in the following paragraphs.

- Scale accumulated on top of and inside the cavity of the shaft's stuffing box in the flooded-disc scrubber. These scale deposits were discovered early enough to prevent binding of the shaft. Modifying the assembly of the stuffing box and reinstalling it in an inverted position (the cavity at the bottom so it cannot accumulate solids) delayed binding. Eventually, however, the shaft did freeze and had to be cleaned out. Other minor scale accumulations on top of the shaft dome and around the tangential nozzles of the flooded-disc scrubber did not obstruct the flow of limestone slurry or flue gas through the scrubber.

- Dilute sulfurous acid condensate caused corrosion in the expansion joints above the reheaters of both FGD modules and on the top row of tubes near the tube sheet on Module B. This corrosion was caused by the accumulation of dilute sulfurous acid condensate in stagnant pockets in the reheater and ductwork. To prevent recurrence of this corrosion problem, the carbon steel ductwork upstream of the reheaters in the Modules A and B was insulated with a flake-glass liner (Ceilcote)

Table 8. RESULTS OF FGD SYSTEM PERFORMANCE TEST RUNS, OCTOBER 2 to 21, 1973

	A-side	B-side	Stack
Particulate concentration inlet, g/m^3 (gr/scfd)	4.569 (1.995)	5.810 (2.537)	
Particulate concentration outlet, gr/scfd	0.0190 (0.0083)	0.0231 (0.0101)	0.2631 (0.1149)
SO_2 concentration outlet, ppm	34	357	236
SO_2 concentration inlet	417	409	
Configuration	Packed	Hollow	B-side hollow
SO_2 removal, percent	92.4	14.4	9.2
Particulate removal efficiency, percent	99.7	99.8	99.7
Gas inlet to FDS, m^3/sec (acfm)	16.9 (214,300)	96.6 (204,600)	96.4 (204,300)
Theoretical inlet gas to FDS, m^3/sec (acfm)	(198,800)	93.8 (198,800)	
Apparent bypass leakage, m^3/sec (acfm)		7.98 (16,900)	
FDS L/G ratio, liters/m^3 (gal./1000 acf)	1.35 (10.1)	1.42 (10.6)	0.78 (5.8)
Tower L/G ratio, liters/m^3 (gal./1000 acf)	6.5 (48.9)		
Gas velocity through tower, m/sec (ft/sec)	2.10 (6.9)	2.05 (6.6)	2.35 (7.7)
Mist entrainment from tower, g/m^3 (gr/scf)	0.000	0.000	NA
Solids entrainment from tower slurry, g/m^3 (gr/scf)	0.011 (0.005)	NA	NA
Pressure drop FDS, kPa (in. H_2O)	3.7 (14.8)	3.9 (15.7)	3.4 (13.5)
Pressure drop tower demisters, kPa (in. H_2O)	0.0	0.0	
Pressure drop reheater, kPa (in. H_2O)	1.3 (5.15)	0.6 (2.30)	

NA - Not applicable.

(Continued)

Table 8. (continued)

	A-side	B-side with packing	B-side without packing
Temperature tower outlet °C (°F)	49 (121)	49 (121)	49 (121)
ΔT reheater °C (°F)	36 (65)	33 (60)	33 (60)
Mist eliminator wash water rate, liters/sec (gpm)	0.8 (12.5)	0.9 (14.0)	0.8 (14.0)
Slurry flow to FDS, liters/sec (gpm)	137 (2170)	137 (2177)	88 (1400)
Slurry flow from FDS, liters/sec (gpm)	83 (1317)	94 (1486)	NA
Limestone feed rate, kg/min (lb/min)		7.5 (16.6)	
Slurry flow from tower tank to FDS tank, liters/s (gpm)		2.1 (32.5)	
Slurry flow from FDS tank to sludge holdup tank, liters/sec (gpm)		4.0 (64.0)	
Tower tank makeup water, liters/sec (gpm)		0	
FDS tank makeup water, liters/sec (gpm)		NA	
Specific gravity (percent solids tower tank)		1.049 (8.3)	
Specific gravity (percent solids FDS tank)		1.102 (14.8)	
Percent solids FDS tank		15.5	
Tower tank pH		6.5	
FDS tank pH		5.2	
Coal consumption, mg/hr (tons/hr)		49 (54)	
Coal heating value, MJ/kg (Btu/lb)		23.9 (10,293)	
Atmospheric pressure, kPa (in. Hg)		85.4 (25.3)	

and the Corten steel expansion joints were replaced with rubber expansion joints. The corroded tube bundle was replaced, and to prevent acid condensate from reaching the new tubes, a trough was installed to divert any condensate away from the tube bundles. It is important to note that corrosion of the reheater by sulfurous acid occurred only in Module B (the module without packing), which has a low sulfur dioxide removal efficiency. Presumably, the higher sulfur dioxide removal efficiency of Module A (the packed tower) prevents significant formation of sulfurous acid condensation.

- Evidence of chloride attack was noted in the liquid-gas centrifugal separator shell below the absorber. To remedy this problem, R-C coated the interior of the vessel with an epoxy material, which later eroded in spots and had to be repaired. The epoxy material also eroded and disbonded below the scrubber disc. Acid resistant brick was installed in this lower section of the absorber and has held up for more than six months.

- Evidence of additional chloride attack has been noted on Module B reheater tubes, probably as a result of the chlorides that are introduced in the well water used to prepare makeup slurry. Table 9 presents the results of a March 1976 chemical analysis of the well water. The spray distribution deflector above the flooded disc failed because of stress-corrosion cracking. The deflector was redesigned by R-C, and the new design is holding up.

- Recently extensive corrosion has occurred in the ductwork leading from the Module B absorber tower exhaust elbow to the reheat tube bundle. The utility has recoated the elbow several times with a Ceilcote liner. An application problem caused repeated failure of the liner. This problem has still not been fully resolved.

- Harmonic vibrations with deflections of as much as 0.1 cm (0.040 in.) occurred in the reheaters. The vibrations were attributed to the vortex effect of an inadequate transition of duct size from the absorber outlet to the reheater shell. To remedy the situation, cross baffles were installed at the reheater entrance. Vibrations also occurred in the Module B booster fan as a result of uneven scale buildup on the fan blades when the unit was idle. The blades were sandblasted, cleaned, and rebalanced to eliminate these vibrations.

- Sediment built up several times in dead spaces in pipelines and valves of idle pumps and also in process lines. This occured when slurry velocities in the pipe were low (during periods of reduced operating rate). This problem was resolved by redesigning some pipes to eliminate potential dead pockets. To prevent valve freezing due to sediment buildup, some valves were repositioned and flush-out lines were installed.

- Some pipe liners eroded (e.g., in the absorber tower pump inlet piping). The erosion was sometimes caused by unsatisfactory liner materials and sometimes by high flow velocities through pipes and fittings. The rubber lining in some pipes cracked, primarily because of defects in fabrication. Piping modifications helped to reduce the erosion problem.

Burning a lower grade of coal (22 percent ash and 0.7 percent sulfur) in the boiler has been accompanied by some plugging in the mist eliminator and tower packing in Module A. Arizona Public Service has not yet verified whether or not this plugging is related to the lower grade of coal. If this buildup of material continues, it appears that the life span of the packing and the mist eliminator may be reduced as much as 50 percent.

The FGD system is capable of accommodating the boiler down to a 50-MW load level without the system's operation being seriously affected or major problems being encountered. Constant flow is maintained in the liquid circuit to prevent solids deposition in the pipelines. A turndown below 50 MW, however, requires that liquid flow be modulated accordingly, and increases the probability of solids accumulating in the pipelines as a result of the reduced liquid flow velocity.

A number of additional minor problems, typical of FGD operations, have been encountered and resolved by normal maintenance and engineering practices. Among these are pump failures; vessel lining failures (requiring recoating); malfunction of solenoid valves in mist eliminator wash system, preventing adequate washing; reheater steam leaks; gas damper adjustments; localized corrosion, erosion, and scaling; liquid leaks in tanks, valves, and pipelines; and expansion joint failures.

Table 9. CHEMICAL ANALYSIS OF CHOLLA SERVICE WATER

Component	Concentration, ppm Well No. 1	Well No. 2
Calcium ion	126.4	120.0
Magnesium ion	40.0	34.2
Bicarbonate ion	219.6	202.5
Sulfate ion	132.0	68.0
Chloride ion	147.0	127.0
Sodium ion	0	0
Total dissolved solids	665.0	551.7
pH	7.55	7.50
Temperature, °C (°F)	18(65)	18(65)

Table 10 summarizes the performace of the FGD system since start-up.

DESIGN AND OPERATION MODIFICATIONS

From start-up to the present, FGD operating procedures have been modified somewhat. The most important changes have occurred in the process control area. The continuous pH sensors were eliminated and manual wet techniques were adopted on a once-per-shift basis. The original density meters were replaced with nuclear units. The utility has adopted the practice of water purging of plugged sensing lines. The mist eliminator wash system, originally designed to spray each quadrant with service water for 12 seconds every 8 minutes, has been changed to spray each quadrant 45 seconds every 30 minutes.

The only major change in the scrubbing system's design that will be incorporated into the Cholla No. 2 scrubbing system, is the use of Inconel 625 in the fabrication of the reheater tubes (316L stainless steel used in Cholla 1).

ECONOMICS

In 1973 dollars, the Cholla 1 FGD system cost APS approximately $6.5 million (or $57/net kW). This figure does not include the cost of such items as limestone storage and milling facilities and sludge disposal (a pre-existing ash pond is used). The figure also does not include additional costs incurred by the system supplier.

Cost of the ground limestone is $19.20 to $23.50 per ton, delivered. (Transportation costs included in these figures are $7.07 to $15.58 per ton, or 37 to 66 percent of the delivered cost.)

The annual cost of the system is estimated to be 2.2 mills/kWh. This figure includes a 23 percent charge on capital investment to account for interest, depreciation, taxes, and other fixed charges. The 1975 and 1976 annual costs of maintenance, including labor and materials, were $183,871 and $216,024. Arizona Public Service believes these maintenance costs are high,

Table 10. PERFORMANCE DATA FOR CHOLLA FGD

SYSTEM: OCTOBER 1973 TO DECEMBER 1977

Period	Reliability, percent			Comments
	Module A	Module B	System avg.	
Oct. 73	Initial operation and testing			Initial operation and testing of the system started on October 2, 1973, and continued for 3 weeks. Particulate and sulfur dioxide removal efficiencies, mist carryover, gas flows, and gas leakage rates were determined.
Nov. 73	Initial operation and testing			
Dec. 73	Commercial operation			The construction and initial testing of the system were completed on December 3. Commercial operation began on December 14.
Jan. 74	97	90	94	
Feb. 74	100	94	97	
Mar. 74	100	66	83	
Apr. 74	66	57	62	System performance from December 15, 1973, to April 15, 1974, was satisfactory. The scrubbing trains were shut down intermittently for replacement of corroded Corten steel expansion joints on the reheater bundles. Module B was out of service from April 15 to 28; Module A was out from April 17 to 27.
May 74	98	99	98	
June 74	100	100	100	
July 74	97	92	97	
Aug. 74	97	97	97	
Sept. 74	95	99	97	
Oct. 74	83	68	76	The system was shut down for an annual boiler and FGD system overhaul.
Nov. 74	100	98	99	
Dec. 74	100	100	100	
1974 Avg.	94	88	91	
Jan. 75	98	99	98	
Feb. 75	96	99	98	

(Continued)

Table 10. (continued)

Period	Reliability, percent			Comments
	Module A	Module B	System avg.	
Mar. 75				
Apr. 75	88	65	76	
May 75	48	40	44	Both modules were out of service most of the month for scheduled repairs and cleaning.
June 75	100	100	100	A substantial amount of plugging was observed in the Module A absorber tower packing. Some plugging was also noted in the mist eliminators.
July 75	97	98	98	One forced FGD system outage resulted from flow restrictions in the FDS recirculation lines because they needed to be cleaned out.
Aug. 75	95	100	98	
Sept. 75	98	97	98	Problems recurred with FDS recirculation lines, requiring additional cleanouts.
Oct. 75	84	55	70	Overhauling of FGD equipment and recoating of vessels accounted for most of the scrubber outage time.
Nov. 75	100	80	90	
Dec. 75	100	100	100	Minor problems encountered during this period included recycle pump failure and malfunctioning of the Module B reheater coil.
1975 Avg.	91	85	88	
Jan. 76	99	99	99	Module A was in service 715 hours, Module B, 654 hours. Some minor valve and plugging was encountered during the period.
Feb. 76				
Mar. 76				
Apr. 76	99	98	98	The FGD system experienced coating failures in the elbow of the exhaust duct leading to the stack.
May 76	76	100	88	During the month Module A experienced corrosion problems in the reheater tubes. The FDS recirculation lines continued to plug up.
June 76	64	39	52	The utility shut down the FGD system for inspection, maintenance, and repairs.

(Continued)

Table 10. (continued)

Period	Reliability, percent			Comments
	Module A	Module B	System avg.	
July 76	100	98	99	The utility completed repairs to the coating in the elbow scrubber exhaust duct.
Aug. 76	100	100	100	
Sept. 76	100	100	100	The boiler was in service the entire month. Module A and Module B service times were 720 and 679 hours.
Oct. 76	56	56	56	Boiler, Module A, and Module B service times were 417, 415, and 277 hours respectively.
Nov. 76	96	98	97	Boiler, Module A, and Module B service times were 720, 682, and 556 hours, respectively. Minor outages were caused by a reheater steam leak and inlet gas damper adjustments.
Dec. 76	98	100	99	Boiler, Module A, and Module B service times were 744, 742, and 498 hours, respectively. Additional adjustments were made to the Module A inlet gas dampers.
1976 Avg.	89	89	89	
Jan. 77	72	93	83	Boiler, Module A, and Module B service times were 744, 532, and 684 hours, respectively.
Feb. 77	99	99	99	Boiler, Module A, and Module B service times were 672, 648, and 591 hours, respectively. The Munters packing in the Module A absorber was replaced. Minor problems included module vessel plugging, corrosion, liquid piping and gas by-pass dampers.
Mar. 77	72	93	83	Boiler, Module A, and Module B service times were 744, 532, and 684 hours, respectively.
Apr. 77	100	100	100	Boiler, Module A, and Module B service times were 638, 635, and 629 hours, respectively.
May 77	87	87	87	Boiler, Module A, and Module B service times were 645, 645, and 645 hours, respectively. The unit was shut down by APS for mid-year inspection, overhaul, and repairs. R-C initiated a forced oxidation test program on the system by forcing air into the FDS scrubber tank and converting all the sulfite to sulfate.
June 77	100	100	100	Boiler, Module A, and Module B service times were 720 hours.

(Continued)

Table 10. (continued)

Period	Reliability, percent			Comments
	Module A	Module B	System avg.	
July 77	97	99	98	Boiler, Module A, and Module B service times were 744, 724, and 734 hours, respectively. Leaks were encountered in the limestone slurry tank and the Module B return line. R-C continued forced oxidation testing.
Aug. 77	97	99	98	Boiler, Module A, and Module B service times were 744, 723, and 734 hours, respectively.
Sept. 77	100	100	100	Boiler, Module A, and Module B service times were 720, 718, and 718 hours, respectively. Problems with leaks in the limestone slurry tank and return line to the FDS tank continued to plague the system.
Oct. 77	100	100	100	Boiler, Module A, and Module B service times were 744, 743, and 743 hours, respectively.
Nov. 77	100	98	99	Boiler, Module A, and Module B service times were 169, 169, and 142 hours, respectively. Boiler was overhauled during the last half of the month. Minor problems with FGD included venturi leaks and a pump expansion joint failure.
Dec. 77	97	91	94	
1977 Avg.	93	97	95	

and they also believe that the high removal efficiencies and reliabilities listed in the report are the result of considerable financial investment on their part.

APPENDIX A

PLANT SURVEY FORM

A. Company and Plant Information

1. Company name: Arizona Public Service Co. (APS)
2. Main office: Phoenix, Arizona
3. Plant name: Cholla Steam Electric Station
4. Plant location: Joseph City, Arizona
5. Responsible officer: L. K. Mundth
6. Plant manager: Cleo Walker
7. Plant contact: Aubry Parsons
8. Position: Assistant Plant Manager
9. Telephone number: (602) 288-3357
10. Date information gathered: April 8, 1976

Participants in meeting	Affiliation
Aubry Parsons	APS
Milton Johnson	APS
H. A. Ohlgren	PEDCo Environmental
G. A. Isaacs	PEDCo Environmental
B. A. Laseke	PEDCo Environmental

B. Plant and Site Data

1. UTM coordinates: _____

2. Sea Level elevation: Sea level

3. Plant site plot plant (Yes, No): _____
(include drawing or aerial overviews)

4. FGD system plan (yes, No): Yes

5. General description of plant environs: Flat and arid desert region, sparsely populated

6. Coal shipment mode: Coal is shipped to the plant by rail from the Gallup, New Mexico, area [165 km (100 miles) east of the plant] and the Window Rock, Arizona, area [145 km (88 miles) northeast of the plant].

C. FGD Vendor/Designer Background

1. Process name: Limestone slurry

2. Developer/licensor name: Research-Cottrell, Inc.

3. Address: Box 750, Bound Brook, New Jersey 08805

4. Company offering process:

Company name: Research-Cottrell, Inc.

Address: P.O. Box 750

Location: Bound Brook, New Jersey

Company contact: James E. McCarthy

Position: Manager, Sales Development

Telephone number: 201/885-7101

5. Architectural/engineers name: Ebasco, Inc.

Address: 2 Rector Street

Location: New York, N.Y. 10006

Company contact:

Position:

Telephone number: 212/785-2200

D. Boiler Data

1. Boiler: 1
2. Boiler manufacturer: Combustion Engineering
3. Boiler service (base, standby, floating, peak):

Base

4. Year boiler placed in service: 1962
5. Total hours operation: Approximately 100,000
6. Remaining life of unit: Approximately 16 years
7. Boiler type: Pulverized-coal-fired, wet-bottom
8. Served by stack no.: 1
9. Stack height: 76 m (250 ft)
10. Stack top inner diameter:
11. Unit ratings:

Gross unit rating: 124 MW

Net unit rating without FGD: 119.5 MW

Net unit rating with FGD: 114.3 MW

Name plate rating:

12. Unit heat rate: 10,202 kJ/net kWh (9670 Btu/net kWh)

Heat rate without FGD:

Heat rate with FGD:

13. Boiler capacity factor, (1974): 85%

14. Fuel type (coal or oil): Coal

15. Flue gas flow:

Maximum: 227 m^3/sec (480,000 acfm)

Temperature: 136°C (276°F)

16. Total excess air: 18 to 20% (3% O_2 in flue gas)

17. Boiler efficiency: 86%

E. Coal Data

1. Coal supplier:

Name: McKinley Mine

Location: Gallup, N.M., and Window Rock, Arizona

Mine location: Gallup, N.M., and Window Rock, Arizona

County, State: McKinley, N.M., and Apache, Arizona

Seam:

2. Gross heating value: 23.6 MJ/kg (10,150 Btu/lb)

3. Ash (dry basis): 13.45 avg.

4. Sulfur (dry basis): 0.52 avg.

5. Total moisture: 14.77 avg.

6. Chloride: 0.01 to 0.04

7. Ash composition (See Table A-1)

Table A-1. ASH COMPOSITION OF COAL AT CHOLLA 1

Elemental Constituents	Percent by weight
Iron	8.10
Aluminum	12.24
Calcium	3.54
Magnesium	2.28
Sodium	0.40
Manganese	0.021
Copper	0.007
Lead	0.001
Nickel	0.001
Chromium	0.007
Zinc	0.010
Barium	0.22

F. Atmospheric Emission Regulations

1. Applicable particulate emission regulation

a) Current requirement: 84.27 ng/J (0.196 lb/10^6 Btu)

AQCR priority classification: _____

Regulation and section No.: Arizona State Dept. of Health Regulation No. 7-1-3.5

b) Future requirement (Date:): _____

Regulation and section No.: _____

2. Applicable SO_2 emission regulation

a) Current requirement: 429.9 ng/J (1.0 lb/10^6 Btu)

AQCR Priority Classification: _____

Regulation and section No.: Arizona State Dept. of Health Regulation 7-1-4.2

b) Future requirement (Date:) _____

Regulation and section No.: _____

G. Chemical Additives: (Includes all reagent additives - absorbents, precipitants, flocculants, coagulants, pH adjusters, fixatives, catalysts, etc.)

1. Trade name: Limestone

   Principal ingredient: $CaCO_3$ (95% minimum)

   Function: Scrubbing agent

   Source/manufacturer: Superior Co., Phoenix, Arizona

   Quantity employed: 110% of stoichiometric

   Point of addition: Absorber recirculation tank

2. Trade name: NA

   Principal ingredient: _____

   Function: _____

   Source/manufacturer: _____

   Quantity employed: _____

   Point of addition: _____

3. Trade name: NA

   Principal ingredient: _____

   Function: _____

   Source/manufacturer: _____

   Quantity employed: _____

   Point of addition: _____

4. Trade name: NA

   Principal ingredient: _____

   Function: _____

   Source/manufacturer: _____

   Quantity employed: _____

NA - Not applicable

Point of addition: _____

5. Trade name: NA

Principal ingredient: _____

Function: _____

Source/manufacturer: _____

Quantity employed: _____

Point of addition: _____

H. Equipment Specifications

1. Electrostatic precipitator(s) NA

Number: None

Manufacturer: _____

Particulate removal efficiency: _____

Outlet temperature: _____

Pressure drop: _____

2. Mechanical collector(s)

Number: _____

Type: Multicyclones (multitube dust collectors)

Size: _____

Manufacturer: Research-Cottrell

Particulate removal efficiency: 75 to 80%

Pressure drop: _____

3. Particulate scrubber(s)

Number: Two

Type: Flooded-disc venturi

Manufacturer: Research-Cottrell

Dimensions: 1.8 m Φ x 13.7 m (6 ft Φ x 45 ft high)

Material, shell: 316L stainless steel

Material, shell lining: Ceilcote flakeglass (lower portion)

Material, internals: None

No. of modules: One per module

No. of stages: One

Nozzle type: See item No. 1, Section M - General Comments

Nozzle size: See item No. 1, Section M - General Comments

No. of nozzles: See item No. 1, Section M - General Comments

Boiler load: 100%

Scrubber gas flow: 113 m^3/sec (240,000 acfm) @ 136°C (276°F)

Liquid recirculation rate: 137 liters/sec (2170 gpm)

Modulation: 50% turndown (50 MW)

L/G ratio: 1.35 liters/m^3 (10.1 gal./1000 acf)

Scrubber pressure drop: 2.5 kPa (10 in. H_2O)

Modulation: Flooded-disc controls throat opening and pressure drop

Superficial gas velocity:

Particulate removal efficiency: 99.2%

Inlet loading: 70.6 g/m^3 (2.0 gr/scf)

Outlet loading:

SO_2 removal efficiency:

Inlet concentration:

Outlet concentration:

4. SO_2 absorber(s)

Number: Two (Module A, packed, Module B, hollow)

Type: Packed tower absorber (Module A)

Manufacturer: Research-Cottrell

Dimensions: 6.7 m Φ x 21.3 m (22 ft Φ x 70 ft)

Material, shell: 316L stainless steel

Material, shell lining: None

Material, internals: Munters Packing

No. of modules: One

No. of stages: One

Packing type: Corrugated sheets of polypropylene joined in a fixed matrix, honeycomb pattern.

Packing thickness/stage: 0.6 m (2 ft)

Nozzle type: Spinner vane

Nozzle size:

No. of nozzles:

Boiler load:

Absorber gas flow: 113 m^3/sec @ 136°C (240,000 acfm @ 276°F)

Liquid recirculation rate: 567 liters/sec (9000 gpm)

Modulation: None

L/G ratio: 6.5 liters/m^3 (48.9 gal./1000 acf)

Absorber pressure drop: 0.1 kPa (0.5 in. H_2O)

Modulation: None

Superficial gas velocity: 2.1 m/sec (6.9 ft/sec)

Particulate removal efficiency:

Inlet loading:

Outlet loading: 0.353 g/m^3 (0.010 gr/scf)

SO_2 removal efficiency: 92% (Module A); 25% (Module B)

Inlet concentration: 420 ppm (Module A); 420 ppm (Module B)

Outlet concentration: 35 ppm (Module A); 315 ppm (Module B)

5. Clear water tray(s)

Number: None

Type: _____

Materials of construction: _____

L/G ratio: _____

Source of water: _____

6. Mist eliminator(s)

Number: Two, one per module

Type: Chevron (1st stage); special design (2nd stage)

Materials of construction: Polypropylene (T-271 and T-41)

Manufacturer: Munters

Configuration (horizontal/vertical): Horizontal

Distance between scrubber bed and mist eliminator: _____

3.7 to 4.6 m (12 to 15 ft)

Mist eliminator depth: 0.3 m (1.0 ft) per stage

Vane spacing: First stage 3.8 cm (1.5 in.); second stage 18.1 cm (7.1 in.)

Vane angles: 45 degree

Type and location of wash system: Intermittent overspray, 15 liters/sec (240 pgm); 45 sec every 30 min/quadrant

Superficial gas velocity: 0.1 kPa (0.5 in. H_2O)

Pressure drop: _____

Comments: Two stages per mist eliminator; two passes in first stage, four passes in second stage. 1.2 m (4 ft) between stages.

7. Reheater(s): Two

Type (check appropriate category): _____

[X] in-line (shell-and-tube heat exchanger, two bundles per exchanger; 316L SS construction)

[ ] indirect hot air

[ ] direct combustion

[ ] bypass

[ ] exit gas recirculation

[ ] waste heat recovery

[ ] other

Gas conditions for reheat:

Flow rate: 231 m^3/sec (490,000 acfm)

Temperature: 50°C (122°F)

SO_2 concentration: 35 ppm (Module A); 330 ppm (Module B)

Heating medium: Saturated steam

Combustion fuel: NA

Percent of gas bypassed for reheat: NA

Temperature boost (ΔT): 22°C (40°F)

Energy required: 2%

Comments: Saturated steam extracted from boiler steam drum at a pressure of 1.8 MPa (250 psig); consumption rate is 9000 kg/min (20,000 lb/hr); rating is 84 GJ/hr (8 x 10^6 Btu/hr).

8. Fan(s) Four: two induced-draft boiler fans and two forced-draft FGD booster fans

Type: Forced-draft paddle wheel (FGD booster fans)

Materials of construction: Mild steel

Manufacturer: Westinghouse

Location: Upstream of FGD, suction side of boiler ID fans

Fan/motor speed:

Motor/brake power:

Variable speed drive: _____

9. Tank(s)

	Flooded-disc scrubber holdup tank	SO_2 absorber towers holdup tank	FGD system sludge holdup tank	Limestone slurry makeup tank
Total number of tanks	one	one (common)	two	one
Tank sizes	3.8 m (12 ft) dia. x 4.3 m (14 ft)	8.3 m (27 ft) dia. x 8.5 m (28 ft)	5.6 m (18 ft) dia. x (27 ft) 8.2 m	
Retiontion time at full load	7 min	5 min	14 hr each	
Temperature	49°C (121°F)	49°C (121°F)	49°C (121°F)	32 : (90°F)
pH	5.2	6.5	5.2	
Solids concentration, percent	15.5	8.3	25	20
Specific gravity	1.102	1.049		

10. Recirculation/slurry pump(s)

Number	Description	Manufacturer	Capacity, liters/sec (gpm)	Materials	Service
3	FDS recirculation	Gould	168 (2670)	Rubber-lined	Two operational/ one spare
3	Absorber recirculation	Gould	587 (9300)	Rubber-lined	Two operational/ one spare

11. Thickener(s)/clarifier(s) NA

Number: None

Type: _____

Manufacturer: _____

Materials of construction: _____

Configuration: _____

Diameter: _____

Depth: _____

ake speed: _____

12. Vacuum filter(s) NA

Number: _____

Type: _____

Manufacturer: _____

Materials of construction: _____

Belt cloth material: _____

Design capacity: _____

Filter area: _____

13. Centrifuge(s) NA

Number: None

Type: _____

Manufacturer: _____

Materials of construction: _____

Size/dimensions: _____

Capacity: _____

14. Interim sludge pond(s)

Number: One (pre-existing fly ash disposal pond)

Description: Solar evaporation and fly ash disposal pond

Area: 283,281 to 404,687 m^2 (70 to 100 acres)

Depth: 1.8 m (6 ft) maximum

Liner type: Unlined

Location: On plant site

Typical operating schedule: Continuous discharge with no recurculation to FGD because of high evaporation rate

Ground water/surface water monitors: NA

15. Final disposal site(s): Pre-existing fly ash disposal pond

Number: NA

Description: _____

Area: _____

Depth: _____

Location: _____

Transportation mode: _____

Typical operating schedule: _____

_____

16. Raw materials production: See item No. 2, Section M - General Comments

Type: None

Number: _____

Manufacturer: _____

Capacity: _____

Product characteristics: Delivered 75% < 200 mesh

_____

_____

I. Equipment Operation, Maintenance, and Overhaul Schedule

1. Scrubber(s)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: Scheduled every 6 months

Cleanout duration: _____

Other preventive maintenance procedures: Complete with each system shutdown

2. Absorber(s)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: Same as scrubbers

Cleanout duration: _____

Other preventive maintenance procedures: _____

Same as scrubbers

3. Reheater(s)

Design life: _____

Elapsed operation time: _____

Cleanout method: Six steam-operated soot blowers run for 5 min each 8-hour shift.

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

4. Scrubber fan(s)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: scheduled every 6 months

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

5. Mist eliminator(s)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: Every 30 minutes

Cleanout duration: 45 seconds, 15 liters/sec (240 gpm)

Other preventive maintenance procedures: _____

_____

6. Pump(s)

Design life: _____

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: Scheduled every 6 months

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

7. Vacuum filter(s)/centrifuge(s)

Design life: NA

Elapsed operation time: _____

Cleanout method: _____

Cleanout frequency: _____

Cleanout duration: _____

Other preventive maintenance procedures: _____

_____

8. Sludge disposal pond(s)

Design life: _____

Elapsed operation time: _____

Capacity consumed: _____

Remaining capacity: _____

Cleanout procedures: _____

_____

J. Cost Data

1. Total installed capital cost: $6.5 million ($57/kW)[a]
2. Annualized operating cost: 2.2 mills/kWh[b]
3. Cost analysis (see breakdown: Table A2)
4. Unit costs
   a. Electricity: 0.2 mills/kWh (including steam)
   b. Water: _____
   c. Steam: 0.2 mills/kWh (including electricity)
   d. Fuel (reheating/FGD process): NA
   e. Fixation cost: NA
   f. Raw material: 0.15 mills/kWh (limestone)[c]
   g. Labor: _____

      _____

      _____
5. Comments _____

[a]Capital cost figure given in 1973 dollars. Additional capital cost expenditures by APS and R-C not included. Includes a 23% charge for capitalization to account for interest, depreciation, taxes, and other fixed charges.

[b]Annual 1975 and 1976 maintenance costs, including labor and materials, were $183,871 and $216,024.

[c]Cost of limestone is $19.20 to $23.50 per ton. This includes a transportation cost of $7.07 to $15.58 per ton.

Table A2. COST BREAKDOWN

Cost elements	Included in cost estimate: Yes	Included in cost estimate: No	Estimated amount or % of total capital cost
A. Capital Costs			
Scrubber modules	X		
Reagent separation facilities		X	
Waste treatment and disposal pond		X	
Byproduct handling and storage			
Site improvements	X		
Land, roads, tracks, substation	X		
Engineering costs	X		
Contractors fee	X		
Interest on capital during construction		X	
B. Annualized Operating Cost			
Fixed Costs			
Interest on capital	X		23 percent
Depreciation	X		23 percent
Insurance and taxes	X		23 percent
Labor cost including overhead		X	
Variable costs			
Raw material	X		$19.20 - $23.5/ton limestone
Utilities	X		0.2 mills/kWh
Maintenance	X		$183,871 (1975), $216,024 (1976)

K. Instrumentation

A brief description of the control mechanism or method of measurement for each of the following process parameters:

- Reagent addition: _____

  _____

- Liquor solids content: _____

  _____

- Liquor dissolved solids content: _____

  _____

- Liquor ion concentrations

  Chloride: _____

  _____

  Calcium: _____

  _____

  Magnesium: _____

  _____

  Sodium: _____

  _____

  Sulfite: _____

  _____

  Sulfate: _____

  _____

  Carbonate: _____

  _____

  Other (specify): _____

  _____

- Liquor alkalinity: See remarks

- Liquor pH: See remarks

- Liquor flow: See remarks

- Pollutant (SO_2, particulate, NO_x) concentration in flue gas: See remarks

- Gas flow: See remarks

- Waste water See remarks

- Waste solids: See remarks

Provide a diagram or drawing of the scrubber/absorber train that illustrates the function and location of the components of the scrubber/absorber control system.

Remarks: A thorough description of the instrumentation/ control loop is provided under Process Description in Section 3 of the report.

L. Discussion of Major Problem Areas:

1. Corrosion: See Operation Problems and Solutions in Section 4 of the report.

2. Erosion: See Operation Problems and Solutions in Section 4 of the report.

3. Scaling: See Operation Problems and Solutions in Section 4 of the report.

4. Plugging: See Operation Problems and Solutions in Section 4 of the report.

5. Design problems: See Operation Problems and Solutions in Section 4 of the report.

6. Waste water/solids disposal: See Operation Problems and Solutions in Section 4 of the report

7. Mechanical problems: See Operation Problems and Solutions in Section 4 of the report

M. General comments:

1. Two-thirds of the scrubbing solution used in the flooded-disc scrubbers is introduced through the hollow shaft of the flooded disc; the remainder is sprayed through tangential nozzles located on the vessel wall.
2. Arizona Public Service is now installing a limestone grinding facility on the plant grounds. This facility will be able to meet the limestone requirements of Cholla 1 and 2 (Cholla 2 will be put in service in June 1978). It will consist of a ball mill capable of grinding 0.6 cm (0.25 in.) limestone rock to 75 percent minus 200-mesh product.

APPENDIX B

PLANT PHOTOGRAPHS

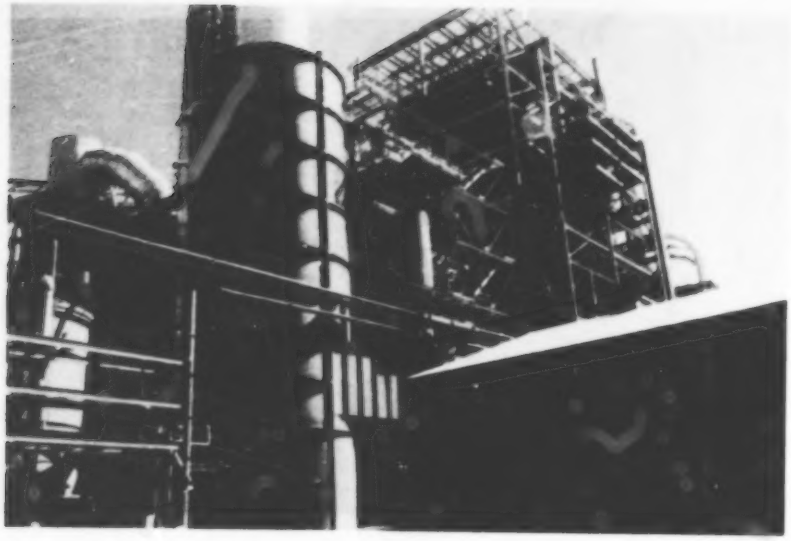

Photo No. 1. General view of the FGD system and boiler for the Cholla No. 1 unit. The two parallel scrubbing trains are featured in the foreground. The boiler is featured in the background. The B-side absorber tower is featured closest to the viewer.

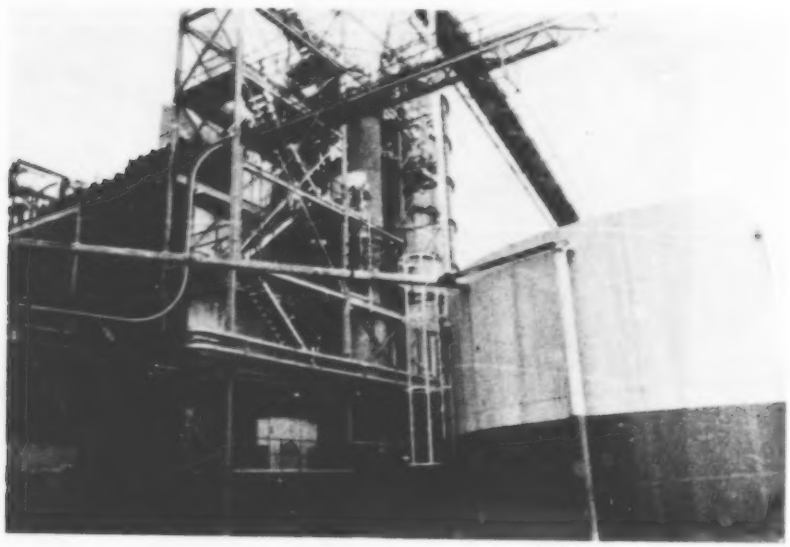

Photo No. 2. Back view of the A-side scrubbing train. Featured in the photo are the induced draft fans, flue gas ductwork, flooded-disc scrubber, absorber tower, and tank.

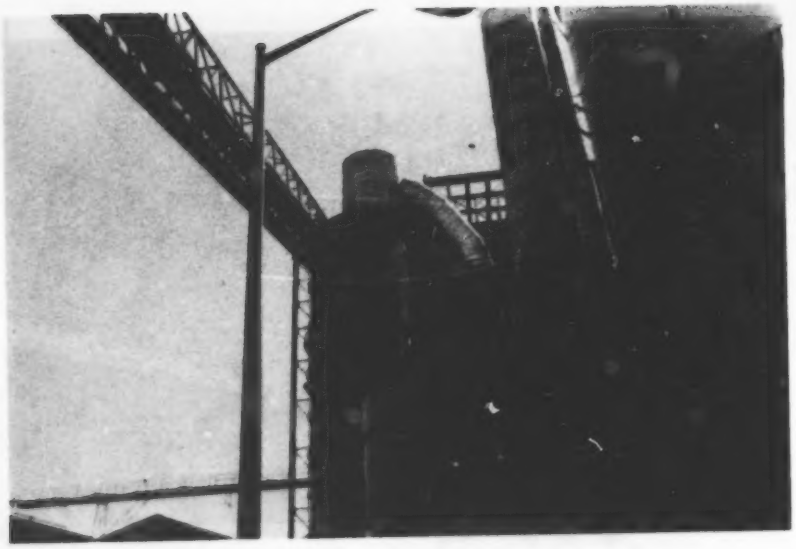

Photo No. 3. Side view of scrubbing facilities. Featured in the photo from left to right are the coal conveyor, absorber tower, ductwork, slurry recirculation tank, stack, and part of the limestone storage silo.

Photo No. 4. Closeup view of the scrubbing train. The flooded-disc scrubber, sump, and absorber tower are featured in the photo from left to right.

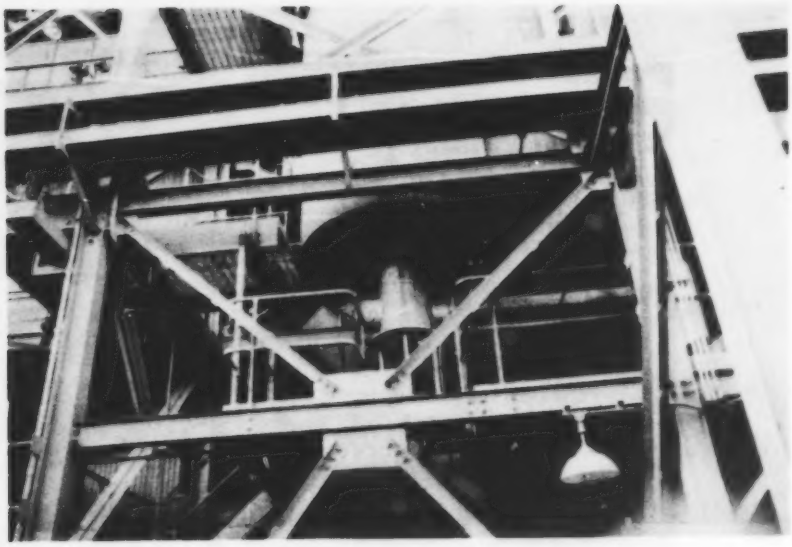

Photo No. 5. Close up view of the base of the shaft which is connected to the flooded-disc located in the throat area of the scrubber.

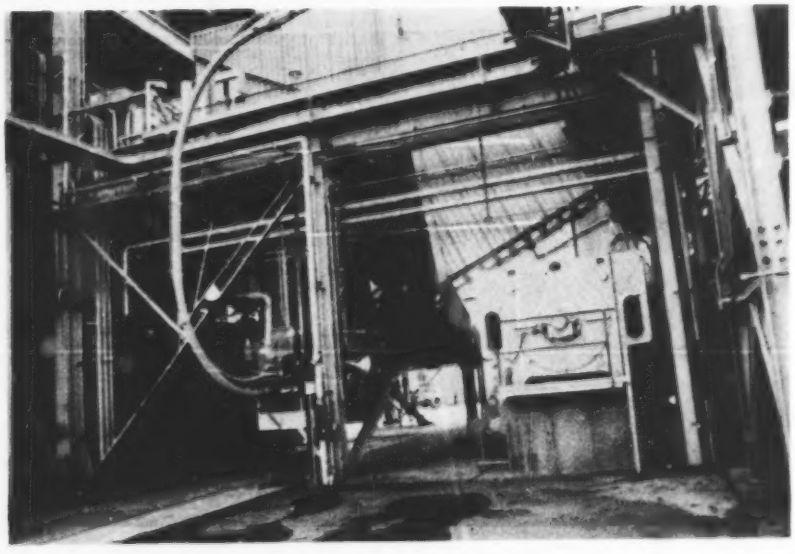

Photo No. 6. Side view of the mechanical collectors and the scrubber induced draft booster fan.

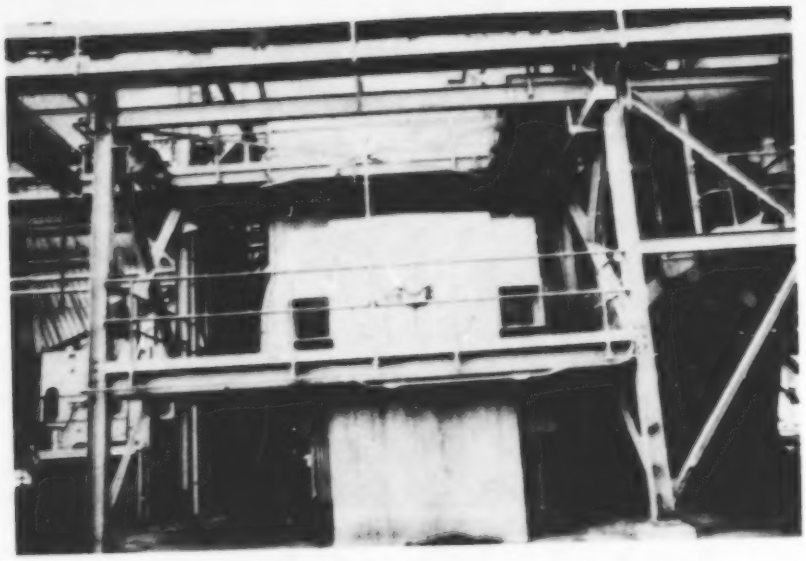

Photo No. 7. Side view of the scrubber induced draft fan.

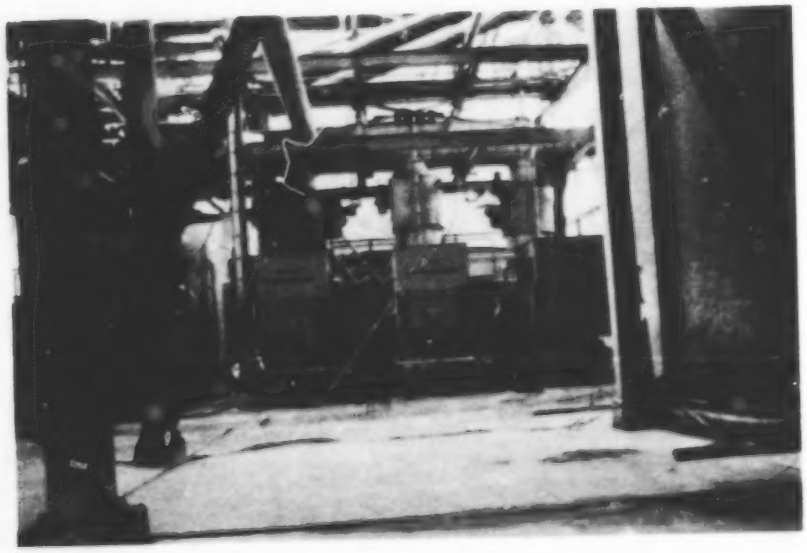

Photo No. 8. View of the battery of absorber tower feed pumps. A total of three are employed for service to both scrubbing trains.

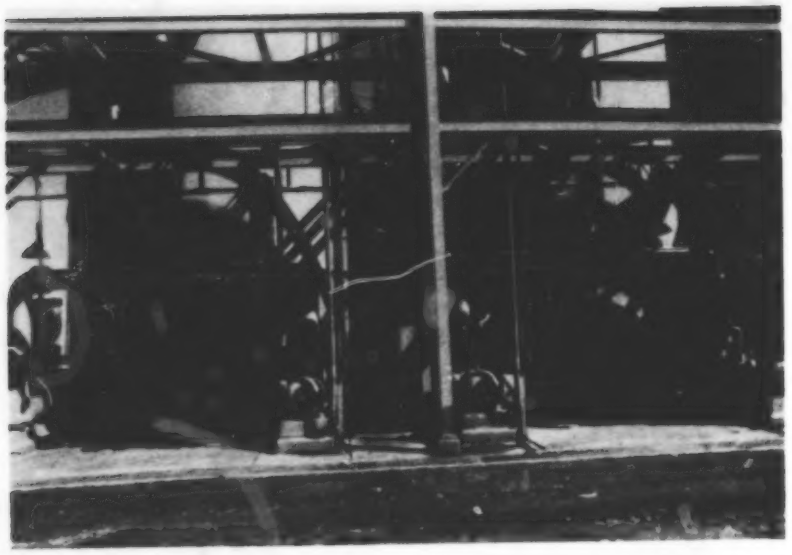

Photo No. 9. Side view of the twin sludge holding tanks showing the discharge pumps and piping.

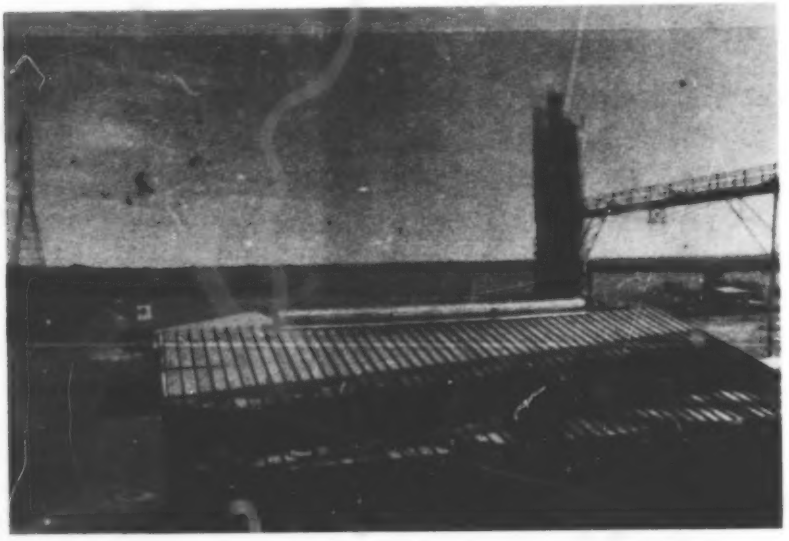

Photo No. 10. View of limestone silo and lake which provides fresh water to the plant. A work shed is located in the foreground.

Photo No. 11. The Cholla station coal receiving, storage and conveying facilities.

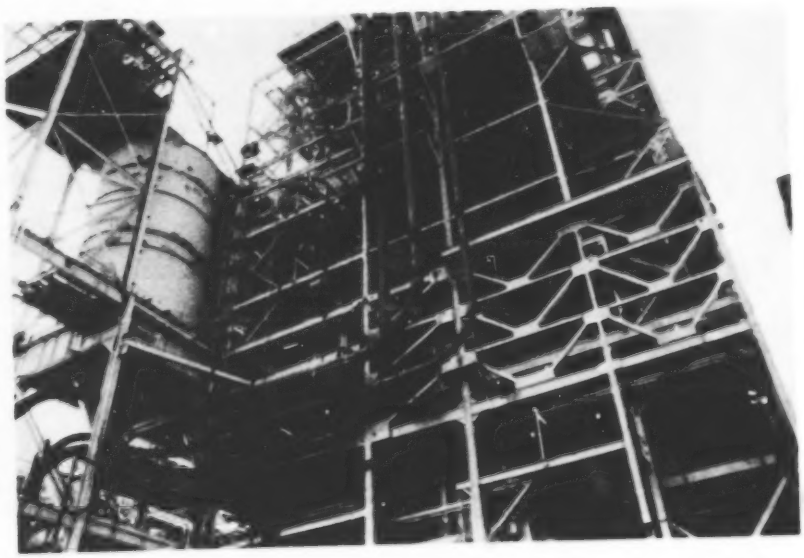

Photo No. 12. View of the boiler for Cholla No. 2. This unit is currently under construction and is scheduled for start-up in June 1977.